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Gas Source MBE Growth and Characterization of TlInGaAs/InP DH Structures for Temperature-independent Wavelength LD Application

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ABSTRACT

TlInGaAs/InP double-hetero (DH) structures were grown on (100) InP substrates by gas source MBE. The photoluminescence (PL) peak energy variation with temperature decreased with increasing Tl composition. For the DH with a Tl composition of 13%, the PL peak energy varied only slightly with temperature (-0.03 meV/K). This value corresponds to a wavelength variation of 0.04 nm/K and is much smaller than that of the lasing wavelength of InGaAsP/InP distributed feedback laser diodes (0.1 nm/K). TlInGaAs/InP light emitting diodes with 6% Tl composition were fabricated and the small temperature variation of the electroluminescence peak energy (-0.09 meV/K) was observed at the wavelength around 1.58 μm. The results are promising to realize the temperature-independent wavelength laser diodes, which are important in the wavelength division multiplexing (WDM) optical fiber communication systems.

INTRODUCTION

Wavelength division multiplexing (WDM) technology is very important for optical fiber communication systems to drastically increase transport capacity. However, one of the problems encountered when using InGaAsP/InP laser diodes (LDs) in WDM systems is that the lasing wavelength fluctuates with ambient temperature variation mainly due to the temperature dependence of the bandgap energy. Therefore, LDs in WDM systems are equipped with Peltier elements to stabilize LD temperature. To solve this problem, the use of temperature-independent bandgap semiconductors as an active layer of LDs was proposed [1].

We have proposed III-V quaternary semiconductors, TlInGaP (Thallium Indium Gallium Phosphide) [2, 3] and TlInGaAs (Thallium Indium Gallium Arsenide) [3] as shown in figure 1. TlInGaP and TlInGaAs can be lattice-matched to InP, and cover the bandgap energies corresponding to the 1 μm wavelength range. Furthermore, we pointed out that TlInGaP and TlInGaAs are expected to show the temperature-independent bandgap energy at certain compositions because it is an alloy of semiconductor, InGaP or InGaAs, and semimetal, TlP or TlAs, similar to HgCdTe. CdTe is a semiconductor and HgTe is a semimetal. Temperature-independent bandgap energy was observed for HgCdTe at a Hg composition of 0.48 [4]. Therefore, the LDs fabricated using TlInGaP or TlInGaAs have the potential to operate without changing wavelength irrespective of

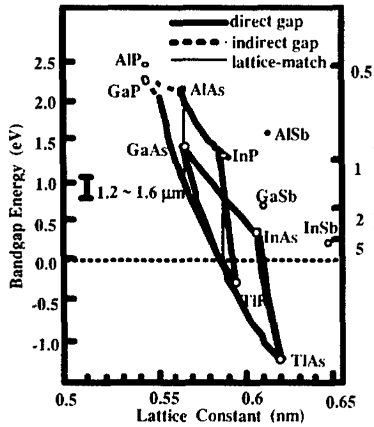

Figure 1. Bandgap energy vs. lattice constant relationship for TlInGaP and TlInGaAs.

ambient temperature variation [2, 3].

We have successfully grown TlInP, TlGaP, TlInGaP, TlInAs and TlInGaAs by gas source molecular-beam epitaxy (MBE) [2, 5-7]. In this paper, the growth of TlInGaAs/InP double-hetero (DH) structures and the observation of very small temperature variation of photoluminescence (PL) peak energy are reported. The results on the electroluminescence (EL) properties for the TlInGaAs/InP light emitting diodes (LEDs) are also described.

GAS SOURCE MBE GROWTH

TlInGaAs/InP DH structures were grown by gas source MBE. Elemental Tl (5N), In (7N) and Ga (7N) and thermally cracked AsH_3 and PH_3 were used as group III and group V sources, respectively. The substrates used were (100) InP. The substrate temperature during growth was 450 °C. Our detailed studies showed that the growth condition for alloys containing Tl is very strict. For example, growth below 400 °C resulted in segregation of Tl, and growth above 460 °C failed to incorporate Tl due to desorption of Tl atoms from the surface. During growth of InP, the reflection high-energy electron diffraction (RHEED) pattern showed (2x4) reconstruction. However, during growth of TlInGaAs the RHEED pattern showed (2x2) reconstruction.

Tl composition was estimated from the double crystal X-ray diffraction data on the TlInGaAs and InGaAs grown with the same In and Ga fluxes assuming Vegard's law and that the lattice constant of TlAs (exact value is not known) is equal to that of InAs. Concerning the lattice constant, Kajikawa *et al.* [8] recently claimed that the lattice constant of TlAs is smaller than that of InAs, though the theoretical calculation by van Schilfgaade *et al.* [9] showed the opposite result. The incorporation of Tl was confirmed

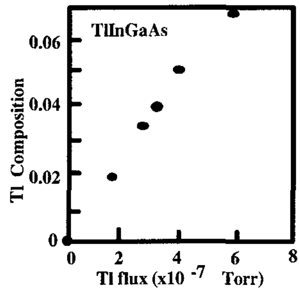

Figure 2. Dependence of Tl composition in TlInGaAs on Tl flux during growth.

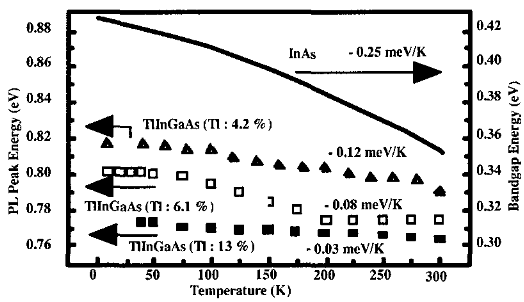

Figure 3. Temperature variation of the PL peak energy for the TlInGaAs/InP DH samples as a function of Tl composition.

with the electron probe micro-analysis (EPMA) measurement. The accuracy of the Tl concentration by EPMA was not sufficient under our experimental condition, but we measured several % to around 10% of Tl. We also observed the decrease in the RHEED intensity oscillation period during growth of TlInGaAs by the addition of Tl flux, which also indicates the incorporation of Tl into InGaAs. The Tl composition in TlInGaAs was observed to increase with the Tl flux during growth as shown in figure 2.

During the growth of TlInGaAs under our growth conditions, we think that the large part of incident Tl atoms is re-evaporating from the surface and only a small part of them is incorporating into films, very similar to the case of MBE growth of GaN under usual growth conditions. Therefore, a relatively large flux for Tl was supplied in our growth.

PL PROPERTIES

PL measurements were conducted in the temperature range from 10 K to 300 K using an Ar ion laser at 488 nm line as the excitation source. With increasing Tl composition, the PL peak energy was shifted toward lower energy [10].

The PL peak energy of the TlInGaAs/InP DH samples varied only slightly with temperature as shown in figure 3. As the Tl composition increased, the temperature variation of the peak energy decreased. For all the DH samples, the temperature variation of the peak energy was much smaller than that of InAs. It is noteworthy that the bandgap energy (~ 0.8 eV) of TlInGaAs is larger than that of InAs (0.356 eV). In general, the wider bandgap a material has, the larger variation of bandgap energy with temperature. The TlInGaAs/InP DH sample with a Tl composition of 13 % showed very small temperature variation of as small as -0.03 meV/K, which corresponds to the wavelength variation of 0.04 nm/K. This value is much smaller than those of lasing wavelengths for the InGaAsP/InP Fabry Perot LDs (0.04 nm/K) as well as the InGaAsP/InP DFB LDs (0.1 nm/K). The InGaAsP/InP DFB LDs are presently used in the optical fiber communication systems. With further increase of Tl composition, we can expect real temperature-independent bandgap energy or positive temperature-dependence.

EL PROPERTIES

TlInGaAs/InP DH LED samples were composed of (i) a Si-doped n-type InP cladding layer (n=1×10^{18} cm^{-3}), (ii) an undoped TlInGaAs active layer, (iii) a Be-doped p-type InP cladding layer (p=1×10^{18} cm^{-3}) and (vi) a Be-doped p-type InGaAs contact layer (p=1×10^{18} cm^{-3}). Tl composition was 6%. Two types of LEDs were fabricated; one is surface emitting LEDs and the other is edge emitting LEDs. The former has 100 μm-diameter circular p-type electrode on the p-type InGaAs contact layer and the EL light output was detected from the top surface. The latter has 70 μm-wide and 300 μm-length stripe p-type electrode and the light output was detected from the cleaved-edge surface.

Figure 4 shows the temperature variation of EL peak energies for both types of LEDs. Small temperature variation was observed; -0.09 meV/K and -0.088 meV/K. These values

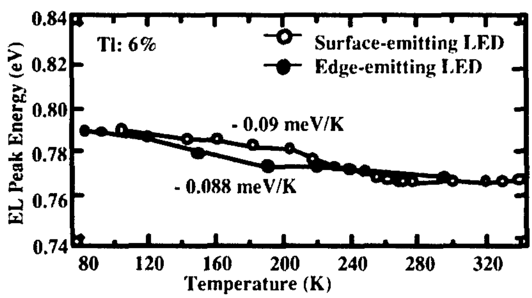

Figure 4. Temperature variation of the EL peak energies for (a) surface-emitting and (b) edge-emitting TlInGaAs/InP DH LEDs.

are the same as that of the PL peak energy for the DH sample with 6% Tl composition (figure 3). The results indicate that the small temperature variation characteristic was

confirmed also on the device level. Therefore, the TlInGaAs/InP heterostructures are promising to realize the temperature-independent wavelength LDs, which are important in the WDM optical fiber communication systems.

SUMMARY

In summary, we have grown TlInGaAs/InP DH samples on (100) InP substrates by gas source MBE. It was confirmed that the temperature variation of the PL peak energy for the TlInGaAs/InP DH sample decreased with increasing Tl composition. The PL peak energy of the 13% Tl DH sample varied only slightly with temperature (-0.03 meV/K). This value corresponds to a wavelength variation of 0.04 nm/K and is much smaller than that of the lasing wavelength of InGaAsP/InP DFB LDs (0.1 nm/K). The TlInGaAs/InP DH LEDs were also fabricated and the similar small temperature variation of the EL peak energy was observed.

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